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PETROLOGY OF THE SOUTH CAROLINA GRANITES[1]

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OUTLINE OF THE GEOLOGY OF THE CRYSTALLINE AREA

The South Carolina area of crystalline rocks extends northwestward from the fall-line, is roughly triangular in shape, and forms a part of the eastern crystalline area which extends southwestward from New York to northern central Alabama.

Until the recently established State Geological Survey of Earle Sloan, this region had received almost no geological study since the state surveys of M. Toumey in 1844–47 (1848 date of final report) and of O. M. Lieber in 1855–60.

The Blue Ridge crosses the extreme northwest corner of the state in a narrow mountainous belt, the higher peaks of which have an extreme elevation of 3,500 feet. Between this mountainous belt on the northwest and the fall-line on the southeast is included the greater part of the crystalline area—the Piedmont province. Its principal physiographic features, in common with the same province toward the northeast and southwest, are the broad rolling upland surface, the valleys carved in the upland, and the minor residuals which rise above the upland. The higher elevations over the region are stated by Sloan to range from 700 to 900 feet above sea-level, with the beds of the major streams averaging 200 feet lower.[2]

Metamorphic crystalline rocks compose the principal part of this region. They include crystalline schists and gneisses derived from both igneous and sedimentary masses, altered chiefly through recrystallization and textural modifications, the most apparent of which is schistosity. The original rocks from which the schists and gneisses are derived are so extremely altered in many places that all trace of their characters is lost.

Among the principal metamorphic igneous rocks are granite-gneisses, hornblende schists, and quartz-sericite schists. In composition and texture the gneisses indicate derivation from original granites. They are usually of light color, fine- to medium-grained texture, and contain, in addition to quartz and mica (biotite with frequently some muscovite), much microcline and some acid plagioclase (oligoclase). The hornblende schists (amphibolites) are composed usually of hornblende and feldspar (albite and oligoclase), some quartz and titaniferous iron ore, with epidote, zoisite, and in places calcite. The quartz-sericite schists are derived from fine-grained bedded porphyry tuffs,[1] corresponding in composition to granite and quartz monzonite. These altered tuffs have been noted chiefly in the immediate vicinity of the gold deposits of York, Lancaster, and Chesterfield counties, and presumably have large areal extent. Where noted in the vicinity of the gold deposits, their alteration has been chiefly one of silicification and recrystallization.[2]

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[1] Published by permission of the Director of the U. S. Geological Survey.

[2] *South Carolina Geological Survey*, 1908, Series IV, Bull. No. 2, p. 505.

Metamorphic rocks of sedimentary origin include chiefly quartz schist, quartz-sericite schist, quartz-biotite schist, sericite schist, and crystalline limestone. The limestones are usually associated ith the schists into which they may grade along their edges within a short distance.[3] They have been noted chiefly in the northwestern part of the state in Cherokee, Laurens, Oconee, and Union counties, where variation is from ordinary blue limestones to white coarse-grained marbles. True foliation is usually most apparent near the margins or edges of the beds. These limestones are usually magnesian, ranging, according to Sloan,[4] from less than 1 per cent. up to 39.72 per cent. of magnesium carbonate. Ordinarily the blue limestones are the more calcareous and the light-colored ones dolomitic. Other minerals than the carbonates, chiefly silicates (amphibole, pyroxene, and mica) and quartz, are contained in the limestones in places.

Granite, pegmatite, and diabase are the principal unaltered igneous rocks. Their general character and field relations to the surrounding rocks indicate that they were intruded subsequent to the principal metamorphism affecting the metamorphic rocks described above. Greatly altered masses of porphyry are intruded into the surrounding schists in places, especially in Chesterfield and Lancaster counties.[1]

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[1] L. C. Graton, *Bull. No. 293*, U. S. Geological Survey, 1906, pp. 15, 16, 78, 79; Geo. H. Williams, *Journal of Geology*, Vol. II (1894), pp. 28 f.

[2] L. C. Graton, *op. cit.*, p. 16.

[3] *Ibid.*, p. 19.

[4] Earle Sloan, *South Carolina Geological Survey*, 1908, Series IV, Bull. No. 2, pp. 256–61.

The granite and pegmatite are closely related in composition, and each is discussed in detail in the subsequent pages of this paper.

Dikes of diabase, ranging up to 200 or more feet in width, are frequently noted throughout the crystalline region, where they may cut any of the rocks described above. These vary in texture from fine- to moderately coarse-grained, and in composition from olivine to olivine-free rocks, are regarded as Mesozoic in age, and represent the latest intrusions in the region.

At Hornsboro, in Chesterfield County, there is a small area of Juratrias sandstones penetrated by diabase dikes—an extension of the Wadesboro, N. C., area into South Carolina.

The geological structure of the South Carolina crystalline region conforms, so far as is known, with other portions of the Atlantic Piedmont province. The rocks are much folded, having northeasterly strikes, and usually dipping at large angles either to the southeast or northwest.

Very little advance has been made toward determining the age relations of the rocks of this region since the work of the earlier geologists. Lieber[2] regarded the rocks of the King's Mountain region as Silurian. Kerr[3] later assigned the rocks of this area to the Huronian. Becker[4] and Nitze[5] considered the rocks of the central Carolinas to be Algonkian. Williams[6] placed the surface volcanic rocks and their associated tuffs as pre-Cambrian. Recent work by Graton[7] in the King's Mountain region resulted in his assigning all the rocks of the region, except the diabase dikes, "Monroe" beds, and sands of the coastal plain, to the pre-Cambrian. In mapping the "Pisgah Folio" in North Carolina, the extreme southern portion of which includes

[1] L. C. Graton, *op. cit.*, pp. 22, 23.

[2] O. M. Lieber, *Geological Survey of South Carolina*, Vol. III, p. 149.

[3] W. C. Kerr, *Geology of North Carolina*, 1875, p. 133.

[4] G. F. Becker, *16th Ann. Rept. U. S. Geological Survey*, 1895, Part III, p. 260.

[5] H. B. C. Nitze, *Bull. No. 3*, North Carolina Geological Survey, 1896, p. 44.

[6] G. H. Williams, *Journal of Geology*, Vol. II (1894), pp. 28 f.

[7] L. C. Graton, *op. cit.*, 1906, pp. 29–31.

a small part of Greenville and Pickens counties, S. C., Keith[1] refers the Henderson granite to the Archean, the Brevard schists, including fine-grained black and dark schists, with lentils of limestone, to the Cambrian, and the Whiteside granite doubtfully to post-Cambrian age.

Excepting the Whiteside granite mapped by Keith in the "Pisgah Folio" as of doubtful post-Cambrian age, Paleozoic granites are yet unknown in the South. For this reason and because of the absence of definite evidence to the contrary, the South Carolina granites are provisionally assigned by the writer as pre-Cambrian in age.

THE GRANITES

DISTRIBUTION

Granite occurs in each of the twenty-one counties composing the crystalline area described above. During the summer of 1908, quarrying was in progress in nine of the twenty-one counties. The principal producing areas extended southwestward across the state along or near the fall-line in Lancaster, Fairfield, Richland, Lexington, and Edgefield counties, and in the extreme northwest portion of the state in Pickens County. Both massive (even-granular and porphyritic) and foliated (schistose) types of granite are frequent over the crystalline area. These are described in detail in the following pages under a number of individual types based chiefly on differences of physical characters and to a less degree on composition.

MINERAL COMPOSITION

The South Carolina granites—mixtures of feldspar, quartz, and biotite—correspond closely in mineral composition with the granites of the southeast Atlantic states in general. They are prevailingly biotite granites. Muscovite, in association with biotite, is a subordinate constituent in a part of the granites of Edgefield, Fairfield, Oconee, and York counties, and is a principal constituent in a reddish-gray granite found near Liberty Hill post-office in Kershaw County. Hornblende has been met with in the granite of one locality only, namely, one mile south of Winnsboro on the Winnsboro-Rockton road. It is subordinate to biotite but is in sufficient amount to designate the granite a hornblende-bearing biotite granite (p. 742).

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[1] Arthur Keith, *Geologic Atlas of the United States*, "Pisgah Folio," No. 147, 1907, "North Carolina–South Carolina."

The great preponderance of biotite granites over others in South Carolina is shown in the following tabulation:

I.	Biotite granite	40
II.	Muscovite granite	1
III.	Muscovite-bearing biotite granite	8
IV.	Hornblende-bearing biotite granite	1
V.	Biotite granite-gneiss	14
VI.	Muscovite-bearing biotite granite-gneiss	4

The feldspars, as indicated in the table of chemical analyses below, include nearly equal mixtures of potassic (orthoclase and microcline) and sodic-lime (plagioclase) varieties. Microcline is equal to and occasionally greater in amount than orthoclase in some sections, and in others it entirely fails. Microperthite, intergrowths of orthoclase with a second feldspar (albite), is very constantly present. Plagioclase near oligoclase (soda-lime feldspar) is present in large amount, and in most cases is equal to or greater in amount than potash feldspar. Examination of the analyses below brings out this fact of high soda content, which is confirmed by the optical studies of thin sections of the granites.

Besides the principal minerals enumerated above, there occur accessory apatite, zircon, magnetite, sphene, and rutile, together with secondary chlorite, epidote, a light-colored mica, and occasionally some other minerals. These are the usual accessories in granite.

CHEMICAL COMPOSITION

The following analyses give a fair idea of the range in composition of the granites described below.

The chemical composition is characterized by a percentage of SiO_2 ranging from 68.70 to 70.70 per cent., with an average for 17 analyses of 69.46 per cent., which is about the normal silica percentage for granites. Of the 18 available analyses of the South Carolina granites, five show more SiO_2 than is indicated in the maximum percentage (Col. VI, 70.70 per cent.) of the table given on p. 735, ranging for the five from 70.90 to 73.26 per cent. The iron oxides, magnesia, and lime show some variation, but on the whole each is reasonably uniform, and is neither very high nor very low. Most of the lime in these analyses is to be attributed to the prevailingly large amount of soda-lime feldspar present in the rocks.

CHEMICAL ANALYSES OF SOUTH CAROLINA GRANITES AND GNEISSES*

	I	II	III	IV	V	VI	VII	VIII
SiO_2	68.70	68.80	68.90	69.79	70.54	70.70	69.95	68.94
Al_2O_3	15.49	15.73	15.75	16.08	14.56	15.63	15.19	15.27
Fe_2O_3	1.10	2.14	1.16	1.01†	1.06	1.14‡	1.20	1.80
FeO	3.73	1.57	1.49	1.66†	1.62	1.24‡	1.61	2.04
MgO	0.86	1.16	0.74	0.53	0.78	0.30	0.69	1.04
CaO	1.70	1.64	2.66	1.73	1.28	2.14‡	1.94	2.24
Na_2O	3.09	3.45	4.76	4.07	3.97	3.86	3.91	3.49
K_2O	3.36	4.54	3.49	4.45	5.37	4.76	4.57	4.31
Igni	0.81	0.33	0.18	0.49†	0.27	0.48	0.39	0.29
TiO_2	0.84	0.45	0.36	0.41†	0.60	0.24‡	0.43	0.50
MnO	Trace	Trace	Trace	Trace	Trace	Trace	0.01	Trace
P_2O_5	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace
SO_3	0.13	Trace	Trace	Trace	0.06	Trace	Trace	0.02
	99.51	99.81	99.49	100.67	100.11	100.49	99.88	99.92

* Earle Sloan, *South Carolina Geological Survey*, 1908, Series IV, Bull. No. 2, pp. 174–225.

† Average of 2 analyses.

‡ One analysis.

I. Porphyritic biotite granite, Clouds Creek, 4.7 miles north of Batesburg, Saluda County.

II. Biotite granite, Cold Point Station, Laurens County.

III. Biotite granite, Jackson's Quarry, 0.5 mile north of Clover, York County.

IV. Average of 3 analyses, including biotite granite from Anderson Quarry, Fairfield County, biotite granite from Excelsior Quarry, Lancaster County, and biotite granite from Leitzsey Quarry, Newberry County.

V. Biotite granite, Benjamin Quarry, 4 miles east of Greenwood, Greenwood County.

VI. Average of 2 analyses, including biotite granite from Flatrock Quarry, Union County, and Keystone Granite Co.'s Quarry, Spartanburg County.

VII. Average of 13 analyses of biotite granites.

VIII. Average of 4 analyses of granite-gneisses, including Ware Shoals, Laurens and Abbeville counties, Beverly Quarry, Pickens County, Pendleton Quarry, Anderson County, and Bates Quarry, Lexington County.

The sum of the alkalies ranges from 6.45 to 9.34 per cent., with an average of 8.48 per cent. for 13 analyses of the South Carolina granites. In the relation between K_2O and Na_2O the former slightly predominates, ranging from 3.36 per cent. to 5.37 per cent. Na_2O

varies in the analyses from 3.09 per cent. to 4.76 per cent., and may equal or even appreciably exceed (Col. III) K_2O. Na_2O shows a total average for the analyses of 3.81 per cent., and K_2O of 4.33 per cent., a difference or excess of 0.52 per cent. of K_2O. The exact composition of the biotite in these granites being unknown, it is not possible to compute accurately the percentage of potash feldspar from the analyses, but most of the K_2O should be calculated as orthoclase.

In each analysis Na_2O has been calculated as albite, and similarly CaO as anorthite. By adding the albite to the anorthite a soda-lime feldspar is obtained which ranges from Ab_3An_1 to Ab_4An_1 in composition, corresponding to a basic oligoclase. This does not completely accord, in every case, with optical study of the thin sections, which frequently show the presence of microperthite, intergrowths of albite with the potash feldspar, and the undoubted presence of Na_2O in the potash feldspar.

In 13 of the 18 available analyses of South Carolina granites, the percentage of Na_2O approximately equals or is but slightly less than that of K_2O; in 5, Na_2O exceeds K_2O; and in only one is there a considerable excess of K_2O over Na_2O. Molecularly, Na_2O exceeds K_2O in each analysis. On the basis then of essentially equal potash and soda, these granities are, to follow Brögger,[1] quartz monzonites and not normal granites.

In defining the limits of intermediate rock-types between granites and diorites, the range of orthoclase in quartz monzonites is stated by Mr. Lindgren[2] as follows: "In the quartz monzonites I would give this mineral (orthoclase) a range from 20 per cent. to 40 per cent., all in an assumed total of 60 per cent. feldspars. The rocks containing more than 40 per cent. orthoclase would then be classed as granites, there being scarcely room for another family between the quartz-monzonites and the granites."

On this basis it will be seen by reference to the table of analyses that if all the K_2O is calculated as orthoclase, the maximum range in this mineral would not exceed 32 per cent., and an average would be about 25.5 per cent. The total feldspar content of these granites, based on the analyses above, averages about 66.8 per cent. proportioned about as follows: 25.5 per cent. potash feldspar and 41.25 per cent. soda-lime feldspar.

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[1] *Die Eruptionsfolge der triadischen Emptiogesteinen bei Predazzo in Sudtyrol* (Kristiania, 1895).

[2] "Granodiorite and Other Intermediate Rocks," *Amer. Jour. Sci.*, Vol. IX (1900), p. 279.

Attention is further directed in the analyses to the constant presence of titanium in very appreciable amount, ranging in the form of TiO_2 from 0.24 to 0.48 per cent. The microscope indicates its principal sources to be in sphene and titaniferous iron oxides, and to some extent as rutile filaments in the quartz. Manganese and phosphorus are noted, usually in traces only.

TYPES OF THE GRANITES

All the granites are biotite granites, muscovite being frequently present in subordinate amount and hornblende failing entirely except in a single locality. They vary in structure from massive to schistose, and in texture from even-granular to porphyritic rocks, and may be grouped on this basis into (1) even-granular massive granites, (2) porphyritic granites, and (3) schistose or foliated granites—granite-gneisses.

The even-granular and porphyritic granites are textural variations of the same rock-mass and are sometimes indicated in the same quarry, but, in such cases, the porphyritic texture is likely to be of a less emphasized or pronounced type than is observed in parts of Georgia and North Carolina. The granite-gneisses have closely similar chemical and mineral composition to the massive granites, from which they were derived and from which they differ principally, in pronounced schistose structure secondarily induced in them by dynamic metamorphism.

PETROGRAPHY

EVEN-GRANULAR GRANITES

General characteristics.—The even-granular granites have wide but variable distribution throughout the crystalline area of the state. They vary from fine- to medium-grained rocks in texture, less often coarse-grained, and are usually some shade of gray in color—light, medium, and dark blue-gray shades being frequent. In many localities a part of the feldspathic constituent is either of slight or pronounced red color, which imparts a mixed reddish-gray color to the rock, the depth of which is proportional to the intensity of red color of the feldspar.

The even-granular granites are described below under the following types, based on differences which are best brought out under the individual descriptions: The Winnsboro types (including light gray and dark-blue gray), the Greenwood–Cold Point gray, the Bowling Green–Clover light gray, and the Columbia red gray.

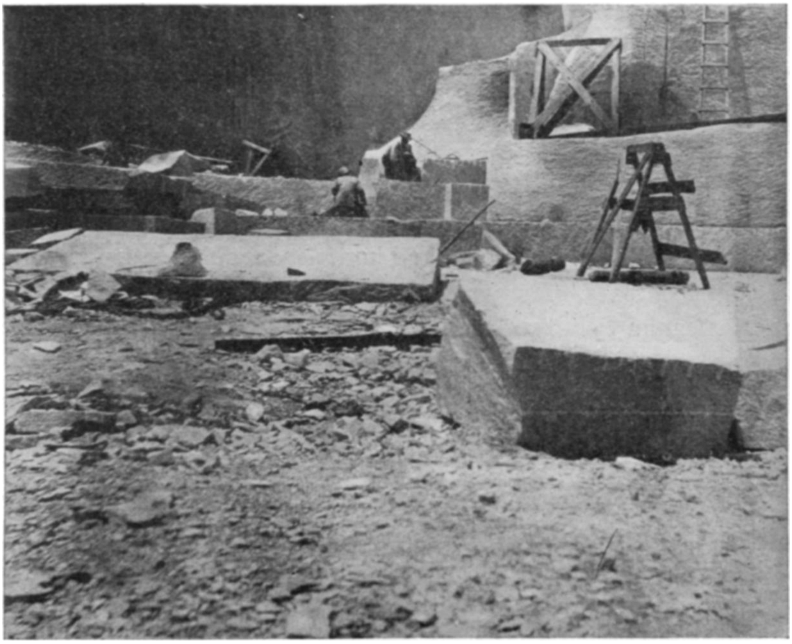

FIG. 1.—Rion Quarry of the Winnsboro Granite Corporation, South Carolina.

The Winnsboro types.—The granites near Winnsboro in Fairfield County are of three varieties, which strongly contrast with each other in hand specimens but are essentially similar mineralogically. One of these is a hornblende-bearing biotite granite, described on p. 742, and is more coarsely crystalline than the other varieties, which are biotite granites. Based on difference of color, the biotite granites are known to the trade as (1) the Winnsboro light gray, and (2) the Winnsboro dark-blue gray, the first being extensively quarried for general building purposes, the latter for monumental stock. These do not differ essentially in mineralogy but bear no resemblance to each other in the hand specimens.

The light-gray variety (Figs. 1 and 2) has no closely similar type, except mineralogically, in the South. Quartz, orthoclase (partly intergrown with albite as microperthite), microcline, oligoclase, biotite, apatite, zircon, and iron oxide, with the usual secondary minerals, make it up. Microperthite and micropegmatite are abundant. Micropoikilitic structure (inclosures of irregular rounded quartz, feldspar, and quartz-feldspar intergrowths—micropegmatite) is rather characteristic of the larger feldspar individuals.

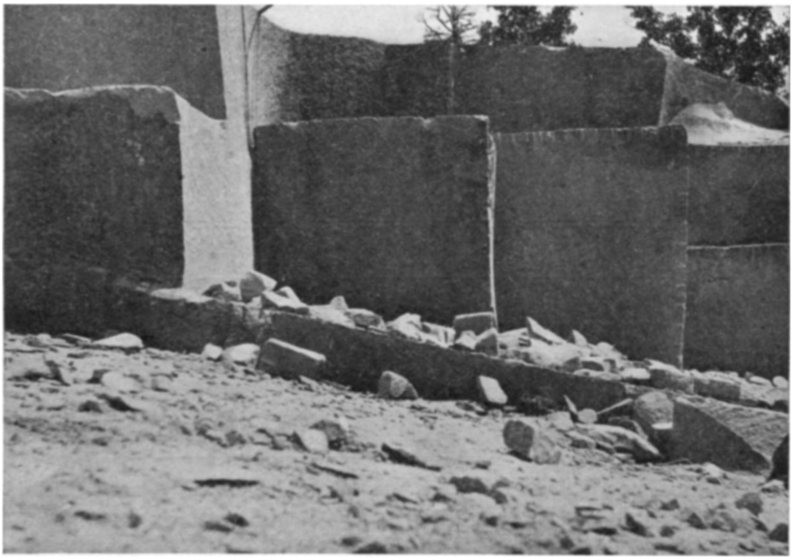

FIG. 2.—Near view of a part of quarry face shown in Fig. 1.

The dark blue-gray variety of fine crystallization has many closely similar representatives, chief among which are the granites of the Excelsior Quarry in Lancaster County and near Newberry in Newberry County, S. C.; the Oglesby-Lexington dark blue-gray granite of Elbert and Oglethorpe counties, Ga.;[1] the Mooresville fine-grained granite in Iredell County, N. C.;[1] and the Richmond-Fredericksburg dark blue-gray granite in Virginia.[2] The granite of the Guilford and Waltersville Quarry near Guilford, Md., is somewhat similar, but is of lighter color and coarser crystallization. As would be expected, these granites may show minor variations in texture and color, but these are so slight that but little difference can be discerned between them in the hand specimens. Orthoclase, much microcline, oligoclase, quartz, biotite, apatite, zircon, and magnetite make up the principal primary minerals composing the Winnsboro blue-gray type of granite.

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[1] *Georgia Geological Survey*, 1902, Bull. No. 9A, pp. 188–224; *Amer. Geologist*, Vol. XXVII (1901), pp. 202, 203.

An average of three analyses of the Winnsboro dark blue-gray type of biotite granite from South Carolina is given below in Col. I and is compared with analyses of the similar type from Georgia (Col. II) and North Carolina (Col. III).

	I	II	III
SiO_2	69.79	69.59	66.01
Al_2O_3	16.08	16.84	17.44
Fe_2O_3	2.85	1.24	5.62
MgO	0.53	0.76	1.11
CaO	1.73	2.67	1.44
Na_2O	4.07	4.77	5.06
K_2O	4.45	4.93	3.16

I. Average of 3 analyses of biotite granite from Anderson Quarry, Fairfield County, Excelsior Quarry, Lancaster County, and Leitzsey Quarry, Newberry County, S. C. *South Carolina Geological Survey*, 1908, Series IV, Bull. No. 2, pp. 252–54.

II. Average of 2 analyses of biotite granite from Diamond Blue Granite Co.'s Quarry, Oglethorpe County, and Hill Quarry, Elbert County, Ga. *Georgia Geological Survey*, 1902, Bull. No. 9A, pp. 191, 241.

III. Biotite granite from Johnson Quarry, near Mooresville, Iredell County, N. C. *North Carolina Geological Survey*, 1906, Bull. No. 2, p. 84.

It will be observed from the analyses that Na_2O and K_2O are essentially equal in the South Carolina and Georgia granites of this type, and in the similar North Carolina type Na_2O greatly exceeds K_2O. Calculating CaO and Na_2O in the analyses to anorthite and albite the following percentages of these minerals are obtained: South

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[1] *Journal of Geology*, Vol. XII (1904), pp. 392, 393; *North Carolina Geological Survey*, 1906, Bull. No. 2, pp. 81–85.

[2] *Bull. Geol. Soc. Amer.*, Vol. XVII (1906), pp. 528, 529.

Carolina, 8.62 per cent. anorthite and 35.11 per cent. albite, corresponding to Ab_4An_1; Georgia, 13.34 per cent. anorthite and 40.35 per cent. albite, corresponding to Ab_3An_1; North Carolina, 7.23 per cent. anorthite and 42.44 per cent. albite, corresponding to Ab_6An_1. The ratio of potash to soda-lime feldspar in the Winnsboro dark blue-gray type of granite is: South Carolina, 1:1.7; Georgia, 1:1.9; North Carolina, 1:2.6.

The gray granites from Columbia, Pacolet, and near Carlisle in Union County, S. C., vary from the type of the Winnsboro blue-gray granite chiefly in lighter color and coarser crystallization. Hand specimens of the granite from the different localities contrast strongly with each other in many cases, but they are essentially similar in mineral and chemical composition.

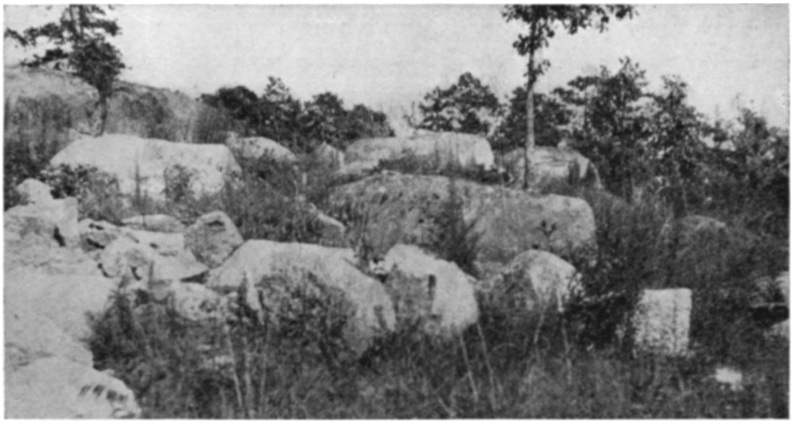

FIG. 3.—Bowlder outcrop of the Winnsboro Granite Corporation's light-gray granite at Rion, Fairfield County, S. C.

The Greenwood–Cold Point types.—The granites at Quarry in Greenwood County, and at Cold Point farther north in Lancaster County, though essentially similar mineralogically, are of two varieties which bear but slight resemblance to each other in the hand specimens. The granite at Quarry is more coarsely crystalline with bluish opalescent quartz, while the Cold Point variety is more finely crystalline and the quartz varies from colorless to moderately dark smoky in color. The feldspars in both varieties (gray granites) are of a faint reddish cast which is more pronounced in the Quarry granite. The principal minerals in these granites are orthoclase (partly intergrown with albite as microperthite), microcline, plagioclase near oligoclase, quartz, biotite, sphene, apatite, and zircon, with the usual secondary minerals which result from the partial alteration of feldspar and biotite. Microcline and plagioclase are present in largest amount. Quartz and feldspar are partly intergrown in granophyric structure, indicating overlapping in the periods of crystallization of these minerals. Carlsbad twins of the potash feldspar are noted both in hand specimens and under the microscope.

Chemical analyses of these granites are given in Cols. II and V in the table of analyses on p. 735. The principal constituents in each analysis are here given for convenience of ready comparison.

	Cold Point Laurens County	Quarry Greenwood County
SiO_2	68.80	70.54
Al_2O_3	15.73	14.56
Fe_2O_3	2.14	1.06
FeO	1.57	1.62
MgO	1.16	0.78
CaO	1.64	1.28
Na_2O	3.45	3.97
K_2O	4.54	5.37

A comparison of these analyses shows the Quarry granite to be slightly more acid and to contain about 2 per cent. more of total alkalies. In both, the percentage of K_2O exceeds that of Na_2O by a fraction more than 1 per cent., but molecularly the latter exceeds the former.

The granite exposed along the road one mile south of Winnsboro in Fairfield County varies but slightly from the Quarry type, the principal difference being the presence of additional hornblende to biotite in the former, which is apparent only in thin sections. As previously stated on p. 733, this is the only granite in the state studied by me in which hornblende occurs. Its principal minerals are orthoclase, microcline, oligoclase, quartz, biotite, hornblende, apatite, zircon, sphene, and the usual secondary accessory minerals. A part of the orthoclase is intergrown with plagioclase (albite) as microperthite. Of the feldspars, microcline and plagioclase are present in largest amount. Micropoikilitic and granophyric structures are common to the feldspars.

The Bowling Green–Clover light-gray granite.—The extensive granite area in the northern central part of York County in the vicinity of Bowling Green and Clover is a medium-textured light-gray biotite granite, closely similar in mineralogy, color, and texture to the Mount Airy granite in Surry County, N. C. It varies from even-granular to porphyritic in texture, but in the porphyritic facies of the rock the feldspar phenocrysts are not very abundant and though frequently of large size, and sometimes showing crystal boundaries, they are usually without crystal outline and grade into the similar ground-mass constituent. In common with the porphyritic granites of the southern states, the feldspar phenocrysts of the porphyritic facies of this type inclose shreds of biotite, equal in size to those of the ground-mass.

This granite consists chiefly of orthoclase, microcline, plagioclase (oligoclase), quartz, biotite, occasional muscovite, together with accessory apatite, zircon, and iron oxide, and secondary chlorite, epidote, colorless mica, and kaolin. Both feldspar and biotite show some alteration in the surface portions of the granite, the former appearing white opaque and chalky from partial kaolinization, the latter showing irregular areas of reddish-brown staining from iron oxide immediately adjacent to the biotite from partial leaching. Intergrowths of orthoclase with plagioclase (albite) as microperthite, and of feldspar with quartz as micropegmatite are frequent. The larger feldspar individuals carry frequent inclosures of feldspar chiefly, quartz, and felsdpar-quartz intergrowths (micropegmatite). Microcline exceeds orthoclase in some sections and is much less in others.

A chemical analysis of this type of granite is given in Col. III of the table of analyses on p. 735. Its close similarity in composition to that of the Mount Airy granite, North Carolina, is indicated in the following analyses, p. 744.

The most noteworthy feature in these analyses is the excess of Na_2O over K_2O. On the basis of the percentages of Na_2O and K_2O in the analyses, the York County, S. C., granite contains 53.41 per cent. of soda-lime feldspar corresponding to Ab_3An_1, and the Mount

Airy, North Carolina, granite, 52.71 per cent. The ratio of potash to soda-lime feldspar in the York County granite is 1:2.6; Mount Airy granite, 1:3.6.

	York County South Carolina	Mount Airy North Carolina
SiO_2	68.90	70.70
Al_2O_3	15.75	16.50
Fe_2O_3	1.16	2.34
FeO	1.49	
MgO	0.74	0.29
CaO	2.66	2.96
Na_2O	4.76	4.56
K_2O	3.49	2.45

The Columbia red-gray granite.—The coarse crystalline red-gray granite quarried at the Smith Branch (County) Quarry, two miles northwest of Columbia, is taken as the type. It does not differ essentially in mineralogy from the gray types described above, although it bears no resemblance to them or to any granites in the other southern states, in the hand specimens. The granite of the Casparis Quarry near Lexington and to the north of Batesburg in Saluda County, S. C., differs from this type only in finer crystallization. In each of these localities the feldspar has pronounced red color, which gives to the granite its characteristic shade. More or less tendency toward porphyritic texture is exhibited in this type of granite. Orthoclase, microcline, oligoclase, quartz, biotite, apatite, magnetite, and the usual secondary minerals are present. Twinning on the Carlsbad law is noted in the potash feldspar. A chemical analysis of this type has not been made as yet, but the thin sections indicate the usual richness in soda-lime feldspar.

PORPHYRITIC GRANITES

Porphyritic granites are common over many parts of the crystalline area in South Carolina, but extensive continuous areas in which porphyritic texture is developed are apparently less frequent than in Georgia and North Carolina. Though porphyritic texture is quite freely developed in many of the granite areas, it either grades within rather short intervals into the more dominant even-granular texture or else is not of so pronounced a type. Like the even-granular granites into which they grade, the porphyritic granites are biotite granites. The potash feldspar phenocrysts vary in size, form, and color. They rarely exceed 30^{mm} in length, are both allotriomorphic and idiomorphic in outline, white or pink in color, often twinned on the Carlsbad law, contain inclusions of biotite, and are without marked orientation in any of the areas studied.

Two rather unusual types of porphyritic granite in the southern states, the Clouds Creek blue-gray and the Heath Springs coarse gray granite, are described below.

The Clouds Creek blue-gray granite.—This type of granite, occurring in an extensive belt in the southeastern part of Saluda County along Clouds and Moores creeks, does not resemble megascopically the granite of any known locality in the South. In hand specimens it is not unlike the coarse-textured augite-hornblende-biotite syenite found southwest of Concord in Cabarrus County, N. C., but differs from the latter in containing more quartz and in the absence of augite and hornblende.

The rock is a massive porphyritic biotite granite (quartz monzonite) of blue-gray color, the ground-mass of which consists of anhedra averaging in size from 2 to 10^{mm} (quartz, 4 to 10^{mm}, biotite, 2 to 4^{mm}, and feldspar 2 to $10+^{mm}$). Porphyritic texture is not very pronounced because of the regular gradation of the feldspar phenocrysts into the similar ground-mass constituent without apparent difference in physical characters shown in the feldspar of the phenocrysts and the ground-mass. The quartz is of slight bluish opalescent color. Feldspar is prevailingly blue gray. In places much of it is nearly white, frequently showing a very faint greenish cast. Cleavage is well developed and Carlsbad twinning is common. The feldspar phenocrysts grade into the ground-mass constituent, are of irregular outline (roughly rounded), from 10 to 25^{mm} and more in diameter, usually blue gray in color though frequently nearly white, highly lustrous and cleavable, and contain inclosures of the ground-mass biotite.

Thin sections show microcline, orthoclase (partly intergrown with albite as microperthite), plagioclase near oligoclase, quartz, and biotite, with secondary chlorite, iron oxide, and colorless mica. Carlsbad and albite twinning are frequent in the feldspars which show some alteration to a colorless mica and kaolin. Biotite shows partial alteration to chlorite and iron oxide, the latter segregated in the biotite much after the fashion of inclusions.

A chemical analysis of this type, given on p. 735 in Col. I, is noteworthy because it shows nearly equal percentages of Na_2O and K_2O and molecularly the former exceeds the latter. Calculating the CaO and Na_2O to anorthite and albite, a plagioclase feldspar is obtained corresponding to Ab_4An_1, amounting to 33.54 per cent., which exceeds potash feldspar by 13.52 per cent., were all the K_2O calculated as orthoclase.

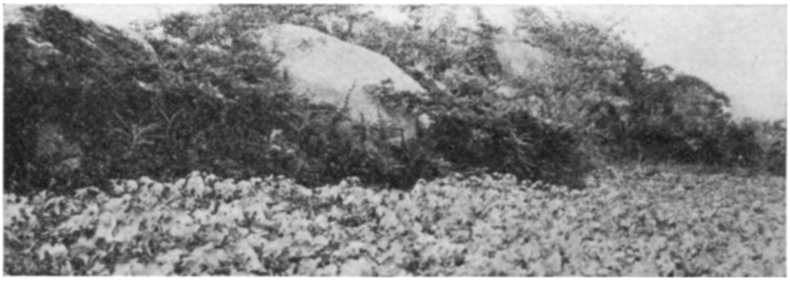

FIG. 4.—Bowlder outcrop of the Heath Springs coarse-grained porphyritic granite. Three miles southwest of Heath Springs, S. C.

The Heath Springs coarse gray granite.—This variety of granite, exposed in large bowlder outcrops (Fig. 4) several miles southwest of Heath Springs in Lancaster County, is closely similar mineralogically, in texture, and in color to the granite of the Wadesboro-Rockingham area[1] to the northeast in Anson and Richmond counties, N. C. The granite is a porphyritic biotite granite of coarse-grained texture and mixed reddish- and greenish-gray color. The feldspars range from 1 to 25^{mm} in size, are highly lustrous and cleavable, mostly of irregular outline, though in part flat-tabular, averaging about 7^{mm} broad by 20^{mm} long, twinned on the Carlsbad law, and partly reddish and bluish green in color. The feldspar phenocrysts grade into the same ground-mass constituent, thus rendering the porphyritic texture less pronounced, and inclose plates and shreds of biotite. Quartz, 1 to 7^{mm} in size, inclines to moderate dark smoky color, and biotite, 0.25 to 5^{mm} in areas up to 10^{mm} in size.

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[1] *Journal of Geology*, Vol. XII (1904), pp. 385, 386; *North Carolina Geological Survey*, 1906, Bull. No. 2, pp. 15–20.

Its principal minerals are orthoclase, microcline, plagioclase (oligoclase), quartz, biotite, sphene, apatite, zircon, and iron oxide, with secondary chlorite, epidote, a little colorless mica, and kaolin. The thin sections examined showed soda-lime feldspar (oligoclase) in excess of the potash feldspar (orthoclase and microcline). A chemical analysis has not been made of this granite nor of the similar one from the North Carolina area, but the feldspar content is apparently somewhat above the average for normal granites.

GRANITE-GNEISSES

Gneisses of granitic composition comprise one of the principal rock-types in the South Carolina crystalline region. Many of these were derived from original massive granites, and are invariably of the mica type, usually biotite; sometimes subordinate muscovite is associated with biotite. The granite-gneisses are essentially identical in mineral composition (table of analyses, p. 735) with the massive granites, from which the former differ chiefly in the banded structure secondarily induced into them by metamorphism. The principal minerals are quartz, orthoclase (largely microperthite), microcline, plagioclase (oligoclase), biotite, a little muscovite, apatite, zircon, sphene, and secondary chlorite and epidote. Recrystallization and orientation of the essential minerals result in a schistose structure. The gneissic banding may be regular or irregular and contorted, usually the latter; the bands are of varying thicknesses, and are composed of alternating ones of light- (chiefly feldspar and quartz) and dark- (chiefly biotite) colored minerals. Like the massive granites, the gneisses show similar variation in color and texture (even-granular to porphyritic).

The Beverly granite-gneiss.—This type, a contorted biotite granite-gneiss of medium- to dark-gray color and medium-grained texture, resembles quite closely the granite-gneiss of the Lithonia and Odessadale areas in Georgia,[1] and the Rockyface Mountain area, Alexander County, in North Carolina.[2] It is more coarsely crystalline than the gneiss of the Georgia localities. The minerals are orthoclase, microcline, oligoclase, quartz, biotite, muscovite, sphene, zircon, apatite, iron oxide, and secondary chlorite, epidote, and colorless mica. Orthoclase is partly intergrown with a second feldspar as microperthite. Microcline shows evidence of having been derived in part from orthoclase. Micropegmatite intergrowths as small areas are indicated, and some of the larger feldspar individuals show micropoikilitic structure (inclosures of rounded quartz chiefly). Granulation of the quartz and feldspar is pronounced and orientation of the biotite is usually well marked.

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[1] *Georgia Geological Survey*, 1902, Bull. No. 9A, pp. 78, 79, 125 f.

[2] *North Carolina Geological Survey*, 1906, Bull. No. 2, pp. 160 f.

The South Carolina[1] granite-gneiss (Col. 1) is compared chemically with the Georgia[2] gneisses (Cols. 2 and 3) in the following analyses:

	Beverly South Carolina	Lithonia* Georgia	Odessadale Georgia
SiO_2..........	68.15	75.09	76.37
Al_2O_3.........	14.30	13.86	13.31
Fe_2O_3†.......	5.20	.95	1.21
MgO.........	1.04	.16	0.10
CaO..........	2.80	.98	1.13
Na_2O.........	3.80	3.87	4.02
K_2O..........	3.84	4.87	3.68

* Average of 5 analyses.

† Total iron estimated as Fe_2O_3.

Examination of these analyses shows at once the greater acidity of the Georgia gneisses over the gneiss from South Carolina, in the large excess of silica, and the smaller amounts of lime, magnesia, and iron oxide. In the percentages of alkalies, Na_2O and K_2O, the difference is less apparent. Molecularly, Na_2O exceeds K_2O in each case, but when CaO and Na_2O are calculated to anorthite and albite the difference is more striking. For the South Carolina type total plagioclase is 45.86 per cent., for Lithonia and Odessadale, Ga., 28.05 and 39.10 per cent., respectively. Also, the plagioclase in the Georgia localities is more acid than that from the South Carolina locality.

THE APLITES AND THE PEGMATITES

Aplites.—Aplite dikes are only occasionally met with in the South Carolina granites. They were noted by me only at three localities, namely, at Smith Branch (County) Quarry near Columbia, the Anderson Quarry in Fairfield County, and at the Casparis Quarry near Lexington. In the quarry near Columbia, aplite dikes are rather numerous, ranging up to four feet in thickness. They are uniformly reddish brown in color and so dense and fine-grained in texture that the minerals cannot be distinguished by the naked eye. The principal minerals, under the microscope, are orthoclase, some microcline, oligoclase, quartz, a little biotite, apatite, and secondary chlorite and epidote. At the Anderson Quarry in Fairfield County, the aplites, ranging in thickness from 1 to 12 inches, are banded with pegmatite. They are very fine-grained in texture and of light-gray color, with scant biotite visible to the unaided eye. The minerals are microcline, orthoclase (partly microperthite), some oligoclase, quartz, very little biotite, occasional muscovite, zircon, and accessory chlorite and epidote.

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[1] *South Carolina Geological Survey*, 1908, Series IV, Bull. No. 2, p. 250.

[2] *Georgia Geological Survey*, 1902, Bull. No. 9A, p. 243.

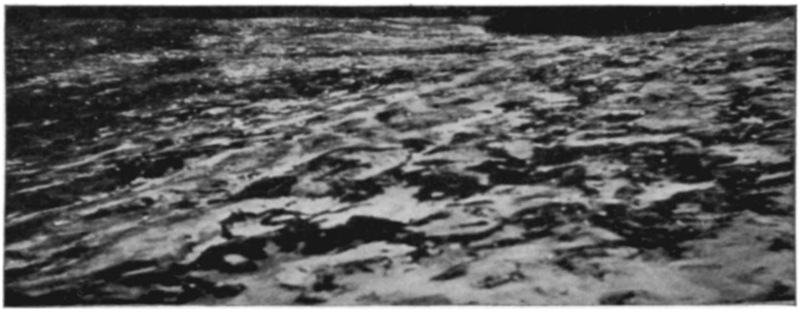

FIG. 5.—Bared slope of granite-gneiss at Beverley Quarry, Beverly, Pickens County, S. C.

Pegmatites.—Pegmatites are frequent over the region and at times attain considerable size. They are granitic, mineralogically, without unusual or rare minerals observed in them, and may cut any of the rocks of the crystalline complex. The mica is usually biotite with frequently some muscovite associated with it. In the quarry at Pacolet black tourmaline is a constituent of some of the pegmatites.

In Abbeville, Anderson, Greenville, Oconee, and Pickens counties the pegmatite dikes vary from 9 to 20 feet in thickness, and, as indicated in the table of analyses below, the feldspar of these pegmatites is the potash variety.

ANALYSES OF FELDSPAR FROM SOUTH CAROLINA PEGMATITES*

	I	II	III	IV
SiO_2	60.79	62.26	65.60	67.30
Al_2O_3	22.57	20.41	19.45	18.21
Fe_2O_3	0.18	0.31	0.71	0.79
MgO	0.23	0.78	0.13	0.14
CaO	0.24	0.19	0.18	0.14
Na_2O	2.72	1.41	2.02	2.41
K_2O	11.01	12.71	11.34	11.14
Igni.	1.90	1.54	0.63	0.06
TiO_2	.....	Trace	Trace	Trace
P_2O_5	0.09	....	....	....
SO_3	Trace	....	Trace	....
	99.73	99.61	100.19	100.19

* Earle Sloan, *South Carolina Geological Survey*, 1908, Series IV, Bull. No. 2, pp. 142–49.

I. Feldspar from pegmatite dike 8.5 miles southeast of Greenville, Greenville County, S. C.

II. Feldspar from pegmatite dike 12.5 miles northwest of Walhalla, Oconee County, S. C.

III. Feldspar from pegmatite dike 3.7 miles N. 70° W. of Pickens, Pickens County, S. C.

IV. Feldspar from pegmatite dike 6 miles N. 55° W. of Central, Oconee County, S. C.

Several varieties of pegmatite were distinguished by Graton[1] in the tin belt of the King's Mountain area, the four most common of which, in the probable order of their formation, are: (1) Pegmatite, usually of light color and not very coarse grained, composed of microcline, quartz, oligoclase, orthoclase, muscovite, with in places numerous small red garnets and ilmenite. Crushing is apparent in much of the rock. (2) Pegmatite of light color, somewhat foliated, with feldspar as the chief constituent. The feldspar consists of orthoclase, intergrown with albite, and separate small individual grains of albite, quartz, and biotite, with associated small prisms of monazite, and in many places flakes of primary graphite. These are sometimes worked in the western part of Cherokee County for monazite. (3) Pegmatite of very light color and fairly coarse grained, with quartz and feldspar as the only constituents in most places, but muscovite and cassiterite become essential constituents locally. Microcline is abundant, penetrated by grains of albite and slender tongues of quartz. (4) Pegmatite of the fourth class is coarse grained and consists chiefly of quartz and muscovite, with feldspar absent or only sparingly present. Feldspar is locally abundant. Cassiterite is an important constituent in places, and spodumene, apatite, and probably lithiophilite are noted.

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[1] L. C. Graton, *Bull. No. 293*, U. S. Geological Survey, 1906, pp. 20–23.

JOINT SYSTEMS

Two systems of joints intersect the granites in the South Carolina quarries, namely, a vertical set and a horizontal set. These do not in all cases have the same degree of development, nor are the two systems always developed in the same quarry. Vertical joints, the commonest type, may have inclinations of as much as 50° to 60° with variable intervals of spacing. In the northeast quadrant the joints which extend approximately north-northeast and east-northeast are of about equal development; in the northwest quadrant those which extend approximately west-northwest comprise the dominant system. Only a few of the joints measured extended E.-W. and N.-S. The system of horizontal joints, which in general follow the surface configuration of the rocks, is less often developed in the granite of the South Carolina quarries than in the granites of the other southern states.